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Diffusion of Academic R&D Capabilities as an Industrial Innovation Policy? – The Development of Israel's IT Industry

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Abstract: In the last decade, three countries have figured prominently as cases of late-late developing countries that achieved worldwide success with their Information Technology (IT) industries: India, Ireland, and Israel. This paper focuses on the Israeli case and argues that unlike India and Ireland, Israel's competitive advantage in the IT industries, is in Research and Development (R&D). The paper's main arguments are that (a) the declared aim of Israel's industrial policy has been to develop exactly such a system of innovation we see in Israel today; (b) however, these policies, focused on diffusion and not on creation of capabilities, were successful only because of the existence of an already sophisticated and extensive R&D capability in the universities – markedly different from other NICs. Looking at the present the paper concludes that the same operational model that led Israel's IT industry to success might now be undermining its future growth.

Keywords: Industrial transformation and development, Innovative capabilities' diffusion, systems of innovation, Information technologies, Science and technology policies
JEL – codes: L5, L6, L8, O0

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Introduction

In the last decade, three countries have figured prominently as cases of late-late developing countries that achieved worldwide success with their Information Technology (IT) industries: India, Ireland, and Israel. This paper focuses on the Israeli case and argues that, unlike India and Ireland, Israel's competitive advantage in the IT industries is in Research and Development (R&D).[1] This competitive advantage in R&D exists in all IT industrial sectors and life sciences and propelled the Israeli high-technology industry to success first in hardware and then in software.

The argument of this paper is that this R&D advantage, historically emanating from Israel's academic research complex, is apparent throughout the Israeli system of innovation and in all stages of technological research. The paper contends that after the early success of defense-related R&D efforts proved the viability of this knowledge, the existence of this academic technological R&D knowledge has allowed Israel to successfully utilize market-failure-focused industry-wide S&T industrial polices. Those policies have sought the diffusion of these capabilities throughout the industrial sector since in the late 1960s.

Therefore, the paper's main arguments are that (a) *the declared aim of Israel's industrial policy has been to develop exactly such a system of innovation that we see in Israel today*; (b) *these policies, focused on diffusion and not on creation of capabilities, were successful only because of the existence of an already sophisticated and extensive R&D capability in the universities; a marked difference with the histories of other Newly*

[1] For analysis of the Indian industry, see Arora et al. 2001a; Arora and Athreye 2002; Arora et al. 2001b; Patibandla and Petersen 2002; for analysis of the Irish industry, see Arora et al. 2001b; Breznitz 2002; O'Gorman et al. 1997; O'Riain 1997a; O'Riain 1997b; O'Riain 1999; O'Riain 2000.

Industrialized Countries. Hence, the Israeli innovation system, while not directly built by these state efforts, was nonetheless greatly assisted in its development by the state.[2]

This paper analyzes and compares the development of the Israeli IT industry following the arguments of the National Innovation System (NIS) literature (Lundvall 1992; Nelson 1993). The NIS literature offers us two interrelated insights in regard to the construction of national industry analysis:

(1) Institutional – different kinds of informal and formal constraints construct different sets of incentives that influence innovative activities. These institutions also influence the way that new technologies are diffused throughout any given industrial system, and define that system's specific R&D and technological paradigms (Dosi 1982). Consequently, the frequency of the creation of new generations of products that are developed using the latest technology.

(2) The best way to analyze these sets of incentives is at the national level, i.e. the distinct relations between actors in the business, finance, state, and educational arenas at the national level best explain the level of innovation throughout the industry and throughout the nation in question(Zysman 1994; Zysman 1996).[3]

Accordingly, the analysis in this paper focuses on the national perspective, and also highlights the role of local market demand for IT and defense R&D in propelling and

[2] Most of the literature about late developers, such as South Korea and Taiwan, emphasis the key role of technology transfer and catching-up in their industrial development history, with the state playing a critical role as facilitator and banker of both, as well as being the main vehicle of technology transfer in Taiwan through the creation of the Industrial Technology Research Institution – ITRI. This is an almost opposite development path to the one this paper argues Israel had utilized. For more about Korea and Taiwan, see Amsden 1989; Amsden 2001; Amsden and Chu 2003; Breznitz Forthcoming; Cheng 1990; Fields 1997; Fuller et al. 2003; Gold 1986; Hong 1997; Park 2000; Wade 1990.

[3] Indeed some writers using the system of innovation approach argue that these systems should be analyzed at different levels, such as the industrial sectors or the region (Braczyk et al. 1998; Breschi and Malerba 1997; Carlsson et al. 2002; Hollingsworth et al. 1994; Kitschelt 1991; Saxenian 1994). However, as the subject of this paper is a specific industry and as the state of Israel, with its small size in land and population, is smaller than some of the regions analyzed by those writers, there is no real disagreement with our analysis.

enabling the development of civilian R&D capabilities. The analysis for this paper was supplemented with 240 interviews conducted with founders of IT companies, VCs, heads of the national and industrial development agencies, civil servants, and academics. These were conducted in Israel, the US, and Ireland between December 1999 and August 2002.

The first part of the paper describes the Israeli IT industry's success and growth in the 1990s and demonstrates its relative strength in R&D by comparing it with the Irish IT industry, the most similar of the emerging country industries. This comparison is especially suitable as in both countries the IT industry is the first case of an indigenous sector attaining worldwide success and spurring large-scale technological entrepreneurship. The paper then elaborates on the claim that this R&D intensity is prevalent in all parts of the Israeli innovation system by analyzing patent data, academic research output, and the composition of internationally publicly traded Israeli science-based companies. The second part of the paper presents a brief economic history of Israel, a description of the development of the IT industry, and the history of Israel's science and technology (ST) industrial policies. I conclude by reflecting on the future of the Israeli IT industry and its prospects.

The Israeli IT industry at present: composition and some international comparisons

Looking at the Israeli IT industry in 2002, we see a landscape of strong growth through the 1990s, based on growing numbers of small and medium sized New-Technology-Based-Firms (NTBF), all of which imitate to a lesser or greater degree the development path of an American start-up company. Even in a comparison to Ireland, the most successful case of IT industrial growth in Europe, we can see that IT industry has

been significantly growing in importance, employing larger percentages of the workforce and contributing significant amounts of total annual GNP growth.

Table 1, Total sales and exports Ireland and Israel, and graph 1 Total employment.

However, one difference that immediately strikes the eye is that the indigenous Irish IT industry is focused almost solely around pure software companies, while the Israeli industry is divided between the older and more developed hardware and electronic sector and the younger pure software sector.[4] Of the two indigenous IT industries, the Irish and Israeli, the Israeli one is the older, with the hardware sector preceding the pure software sector by more than a decade. The Israeli IT industry also followed a very different business strategy from the Irish one. From its inception, the industry was a product-based export-oriented one. As early as 1972, an Elron group company, a medical imaging company named Elscient listed on the NASDAQ less than two years after it produced its first medical imaging device.[5]

Of the two broadly defined sectors of the Israeli IT industry, electronics and hardware and pure software, the electronics and hardware sector is by far the larger. With 55,800 employees and $12.5 billion in sales in 2000, the hardware sector is about four times larger than the software sector.[6] This difference looms even larger when we analyze

[4] Apart from one successful NASDAQ IPO (Parthus, acquired and merged with the IP licensing division of an Israeli company, DSPG), a few mergers (Agilent acquisition of MVT, and PMC Sierra acquisition of Toucan being the prominent ones), 2-3 medium size IC design houses, and about 3 promising start-ups, the indigenous Irish IT industry consists only of pure software companies.

[5] For more on the early electro-medical industry in Israel, see Teubal et al. 1976, and Teubal and Spiller 1977. For a history of the semiconductors history in Israel, see Autler 2000. For a descriptive history of Israel high-technology industry, see Levav 1998. For three accounts which briefly discuss the software industry and the causes of its success, see Ariav and Goodman 1994; Breznitz 2004; de Fontenay and Carmel 2001.

[6] This is based on data supplied by the hardware and software industry associations in Israel as well as the data of the Central Bureau of Statistics. However, the definitions of the software industry are not specified nor are the methods in which this data was gathered. As the SEC filing of the twenty biggest Israeli software companies declared sales of more than $5 billion in both 2001 and 2002, there is a reason to believe that the official data is severely underestimating the real size of the industry.

the data of total R&D financing in Israel and realize that 85% of total R&D expenditures in 1998 were focused solely on the optical and communication electronic sub-sector (Bentur 2002).

The two sectors seem to have followed the same growth trajectories in the 1990s, the software industry growing at an average annual rate of 23%, and hardware at around 15%. However, the average sales per employee figures in the software sector quickly grew to narrow the initial gap between the two, with average sales per employee in the software sector surpassing the hardware figure for the first time in 1997. Furthermore, the average sales per employee figure in the Israeli IT sector compares very well with the American one and is more than twice as big as the Irish one.[7] It is important to note, however, that the dividing line between the two sectors is hardly impenetrable.[8]

Graph 2 sales per employee

The Israeli IT industry is extremely product-oriented in comparison to all the other emerging countries. This can be attested to by the fact that Israel, with a population of six million, has the highest number of publicly traded companies on the American NASDAQ apart from the US and Canada. Moreover, these listed Israeli IT companies operate in all the major technological sectors of the IT industry. Interestingly this competitive advantage in R&D originated in the Israeli academic research system, and as early as 1968, the year in which the state officially started its civilian R&D industrial policy program, Israel topped the international table in academic publication per GDP ratio, a position Israel retains to this day. ***Table 1 – NSB data about here.***

[7] Using NAICS codes the sales per employee figures reported for the US industry in the 1997 census for Software Publishers (51121) were $231,621, and for Software Reproducing Companies (334611) were $156,775. See, www.census.gov/epcd/www/naic/html.

[8] Moreover, many Israeli hardware companies gain the competitive advantage in the market with the aid of superior software components.

Contrary to common opinion, Israel has always enjoyed strong academic involvement in industrial R&D. As early as 1979, a special report on fostering industry-university collaboration written by MIT's Center for Policy Alternatives and Tel-Aviv University's Interdisciplinary Center for Technological Analysis and Forecasting, conducted under the sponsorship of the OCS, elaborate on that fact (Tuler and Rao 1979). This involvement became even more active with the establishment of the MAGNET program in the early 1990s. It is not surprising, therefore, that out of the six largest US patent issuers in the last five years, three have been universities' industrial liaison companies. Moreover, one of the most successful of these, Hebrew University's Yissum, had revenues of 25.6$ million in 2001, competing very well with those of leading American research universities, and higher than those of MIT, Harvard, Johns Hopkins, and Caltech. All of these universities have an annual R&D budget at least 15 times larger than that of the Hebrew University.[9] This importance of the academic sector to industrial R&D and patenting activities is unique not only among emerging countries but also among developed countries.

American IT MNCs spotted this competitive advantage in R&D long ago, leading to another unique feature of the Israeli IT industry in comparison with other emerging countries' IT industries. The usual model of an American MNC starting operation in Israel is almost the exact opposite of the bottom-up development process described in the literature, where a foreign MNC first opens assembly and manufacturing plants, and then starts to develop more technologically advanced operations, culminating with an R&D center. Many if not all of the American MNCs first moved to Israel in order to open R&D

[9] Figures for the American universities taken from the Association of University Technology Managers survey (AUTM 2002).

centers, or bought an Israeli NTBF and transformed it into an R&D center, moving only later, if at all, to manufacturing activities.[10]

The story of Intel, the American IT MNC that currently has the largest number of employees in Ireland and Israel, should serve to highlight the difference between these MNCs' development models and to show the different ways in which MNCs continue to develop their operations in each location in accordance with their global strategy. In 1974, Dov Frohman, a senior Israeli researcher at Intel's California headquarters, decided to return to Israel and accept a professorship in the School for Applied Physics at the Hebrew University of Jerusalem.[11] Intel decided to try to retain Frohman as an employee and opened its first design and development center outside the US in Israel with five employees.[12] In doing so, Intel unintentionally pioneered a model by which many other MNCs started operations in Israel.[13] Over the years the Intel center was highly successful and continuously enlarged its R&D activities. By 2002, it encompassed seven centers. In 1985, Intel Israel also pioneered the first movement of Intel toward CPU fabrication activities outside the US when the first Intel fab in Israel started operations in Jerusalem. In 2000, following the acquisition by Intel of two companies with major R&D centers in Israel, DSPC and Dialogic Israel, Intel's R&D activities evolved into two more product platforms. Beyond these, the activities in Israel of Intel Capital, Intel's venture capital arm, are the largest in term of investment outside the US. In 2000, Intel Israel had

[10] For more about the R&D activities of MNCs in Israel see, Felsenstein 1997.
[11] In 1971, shortly after joining Intel in 1969 and after the first 1kbit DRAM was released, Dov Frohman invented the UVEPROM, an electrically programmable memory that holds the programmed values until erased by intense ultraviolet light. Frohman invented, developed, designed, and fabricated the first UVEPROM.
[12] One must note, though, that opening a small design center is not a capital-intensive high-risk decision like opening a fabrication facility, total investment in the Israeli center was $300,000 (1974 terms).
[13] Over the years Israeli senior R&D mangers in other American MNCs have followed this pattern and returned to Israel to open R&D operations for their MNCs. National Semiconductor and Applied Materials are two prominent examples.

revenues of $2 billion and employed 4,000 people; as of 2002, Intel Israel was responsible for the development of the next generation's laptop oriented CPUs, 3G mobile network products, and a few other critical components of Intel's global R&D strategy.

In 1989, Intel decided to start manufacturing operations in Ireland. The first operations were low-level assembly. The main reason behind Intel's decision to locate in Ireland at the time was the company's fear of an imminent creation of "Fortress Europe" by the EC (now EU) in 1992. A year after the first box assembly operation began, Intel decided to open a fab in Ireland, making Ireland the only other place besides Israel with an Intel fab. Within a few years Intel realized that "Fortress Europe" was not an imminent danger and the box assembly line was closed down. However, fabrication activities continued. Moreover, local management, spurred by the shock of the closure and helped by an Israeli who became the fab manager and built on his experience in Israel, started low-profile R&D activities aimed at the creation of a center of excellence in particular technologies in Ireland.[14] Intel Ireland also managed to lobby Intel HQ to create a special position for Intel Capital in Ireland, which started operations in 2001, and has already invested in a couple of local start-ups.[15]

A short analysis of the international patenting activity, our best proxy for innovative industrial R&D activities aimed at the global market, serves to highlight these differences. ***Patenting activity Tables 3-4 and Graphs 3-5 about here.*** As can be seen

[14] Interestingly, the next and present job of the Israeli in question has been managing Intel Capital Israel and then Intel Capital Europe.

[15] The constructed history of Intel in Ireland and Israel is based on interviews with five executives of Intel and Intel capital in Israel and Ireland, and email communication with Dov Frohman, (Dror 2/6/2002),Wired Magazine "Tech New Promised Land," 1/17/2000, also available on line, http://www.wired.com/news/infostructure/0,1377,33537,00.html, and Intel Israel and Intel Ireland websites: http://www.intel.com/il/ and http://www.intel.com/ireland/.

from Graphs 3 to 5, Israel has one of the highest and fastest growing patent per capita ratios in the NIC groups. In fact Israel is one of only three late-late developing countries that have managed to close the gap in patenting per capita ratios with the advanced economies. Moreover, as Graph 5 shows, Israel's patenting profile points toward substantive innovative activities in a wide array of technologies. Looking at the micro level and sub-sectoral patenting activities, and comparing Israel with the other two emerging countries with an extensive software industry, Ireland and India. illustrate the arguments discussed above. As can be seen from Table 3, Israeli organizations are vastly more active in patenting than their counterparts in Ireland, with each one of the top Israeli organizations issuing more patents than the combined total from all Irish organizations. Interestingly the five American MNCS that are doing extensive patenting in Israel are all hardware semiconductors companies with large telecommunication R&D centers in Israel. Analyzing the top classes of patents, we see that Israeli companies are very active in life sciences, communication and optics hardware, image and data-analysis, and power and energy.

An interesting difference in the historical development of the newest Israeli IT sector, the software industry, is salient when we compare the growth of the software industry in the three locations.[16] It is evident that a major feature of the Israeli software industry is the large role that the local market has played in its development. That market was already well developed in 1984 with $370 million in sales, while export sales were only $5 million. Local demand continued to develop, inducing tremendous growth in local software sales throughout the 1980s and 1990s. To clarify how the local market was already relatively large before the export boom began, it is worthwhile to note that in

[16] For more on the Israeli software industry, see Breznitz 2004.

1991 the local sales of the Israeli software industry were $540 million; only in 1997 did the *total* sales (export and local) of the indigenous Irish software industry reach that level (in nominal terms).[17] Comparing Israel to Ireland, we see that while the size of the Israeli software industry in the 1990s was significantly larger, Israel's exports became larger than its local sales only in 1997, whereas Ireland's exports for most of the 1990s were around 60% of total sales.[18]

The last difference on which we should focus in this paper is that of the development paths of the venture capital industry. Two important differences are the sources of capital and the VC management companies. The major source of financing for Israeli VC funds is the US, with smaller amounts of money coming from Asia and Europe, and still smaller amounts from Israel itself. Moreover, almost all of the big funds maintain offices in the US, and all claim to have close working ties with US VCs and big technology companies. In addition, the majority of general and managing partners of most of the VC firms come from the IT industry. In Ireland, most of the financing for the Irish VC funds originates in Ireland itself or from European investors, with only one fund raising a substantial amount of money in the US. In addition, many of the funds are tied to established banks or financial institutions, and only very few of the managing and general partners have any industry experience, with the average partner profile being in accounting or management consulting.

[17] In real term the parity was probably reached only in 1998.
[18] It is interesting to see, however, that local sales had gained in importance in Ireland while stabilizing in Israel. This might point to the fact that in Israel the market for IT was already well developed by the second half of the 1980s, giving the Israeli software industry the needed spur and testing ground to move forward. In Ireland an opposite process seemed to occur, with the export based IT boom prompting the local market, which was underdeveloped (the sales by MNCs in Ireland seems to strengthen this argument rising from less than $40 in 1997 to almost $1 billion in 2000).

The Development of the IT industry and Israeli ST Industrial Policies

This part of the paper describes the historical development of the IT industry. It then presents a brief economic history of Israel that serves as background for analyzing and describing the development and changes in Israel's ST industrial policies and the intricate interplay between private market and state initiatives throughout the historical development of the IT industry in Israel. The aim of this section is to strengthen the paper's main argument about the critical importance of domestic academic R&D capabilities in Israel, and that the state's policies focused on diffusion and not on capability creation and/or technology transfer.

The history of the IT industry in Israel

The official history of IT and computing in Israel began before the creation of the Israeli state as an independent national identity. In 1947, the advisory committee of the Applied Mathematics Department of the Weitzmann Institute (then known as the Seiff Institute), consisting of Albert Einstein, Hans Kramer, Robert Oppenheimer, John Von Neumann, and Abram Pais, recommended that the institute build an electronic digital computer, making Israel the first state-to-be to commit itself to computing (Ariav and Goodman 1994). However, the 1948 War of Independence and the continuing security threats quickly propelled the development of IT in Israel onto a different track. While the Weitzmann Institute of Science continued to develop three generations of scientific computers called the 'Golems', the defense apparatus and the state bureaucracy very quickly became the torchbearers of IT development in Israel.[19]

[19] For more about the impact that the Israeli military had on the software industry, see Breznitz 2003.

Probably the first unit in the Israeli defense complex that started to develop and use IT was RAFAEL (the Hebrew abbreviation of Armament Development Authority).[20] RAFAEL, the first, leading, and for many years almost the only body in Israel that did application-oriented high-tech R&D, had already started to use computers in the 1950s. In 1956, RAFAEL, then still a part of the Israeli Defense Force (IDF), developed an analog computer. In 1959, a more sophisticated analog computer, "Itzik," was developed in order to enable larger scale simulations. At the end of the 1950s, RAFAEL developed a few digital computers.[21]

RAFAEL itself was organized until the early 1990s more as an applied academic institution than as a company. Its researchers were considered academics and were granted all the educational benefits of full-time academic staff including a full academic sabbatical every seven years, which most of them spent outside Israel in leading academic universities or IT companies. Moreover, RAFAEL sponsored graduate academic education for its employees both in Israel and abroad, amounting to more than a few thousand graduate degrees in Israel, and a few hundred in top US engineering schools like MIT and Stanford; to which these graduates returned regularly as visiting scholars. Some of RAFAEL's people have also been lecturing regularly at the Technion, Israel's leading engineering school. In the early 1950s, a whole division was taken from

[20] As can be seen in table 3, RAFAEL is still one of the leading innovative organizations in Israel, as measured by international patents issuer.

[21] The story behind the formation of RAFAEL is also of interest as it illuminates the significant influence and importance that prominent scientists had on public policy in the decades before and after Israel's independence. The initiative to create a special "science corps" was presented by two professors, Aharon Katchalski (the brother of Ephraim head of the 1968 Katchalski committee) and Yuchanan Rutner, to David Ben-Gurion, the leader of the biggest Zionist organization in pre-independence Israel and its first Prime-Minister, before the 1948 independence war. In 1958, the science corps were separated from the Israeli Defense Forces and another prominent bio-chemist from the Weitzman institute, Aharon Bergman, stayed on as its first head (with Munya Mardor as its first MD). For a history of RAFAEL's first years, see Mardor 1981.

RAFAEL and given to the Weitzmann Institute where its people became part of the institute's academic staff.

RAFAEL and the people behind its formation played two other important roles, in addition to being an important source of information diffusion in areas of science and technology and R&D management (for example, RAFAEL pioneered the use of operations research and project management techniques like P.E.R.T in Israel), and generating spin-offs. First, the leading scientists who founded RAFAEL were the same people who formulated Israel's science-based industrial policy at the end of the 1960s. Second, RAFAEL was used by the state as an incubation center with which it "infected" other defense and civilian companies and organizations with IT R&D capabilities. The most important of these were: the creation of the Israeli military computer unit (MAMRAM) in 1960 (Breznitz 2003); the first attempt in 1962 to upgrade the Israeli Aircraft Industries (then known as Aircraft Maintenance Corporation) into a high-technology company with the relocation from RAFAEL of the entire project team that developed the Gabriel – the first Israeli sea-to-sea radar guided rocket; and last but not least the creation, in a joint venture with the Elron group, of a high-tech start-up called Elbit in 1966, the technological base for which was created by the relocation of the entire digital computer development team of RAFAEL to Elbit.[22]

In the private market, two interesting parallel developments occurred. First, while most of the banks and investment companies behaved in a way similar to their Irish counterparts and did not agree to invest in the IT industry, there was one critical

[22] Elbit's first product was a mini-computer that competed head to head with Digital's. Later Elbit moved toward more defense-oriented markets and is now Israel's largest defense high-technology company. In 1983 Elbit first listed on NASDAQ, and as of 2002 three of Elbit's companies -- Elbit Medical imaging, Elbit Ltd. and Elbit Vision system -- are listed.

exception: the Discount Bank investment group, now known as Discount Investment. At the time, the discount group was called the Israeli Company for Investment and Finance and was headed by Dr. Augusto Levi. Italian born and educated, Dr. Levi decided to follow the export-oriented industrial investment model of Italian banks. At the beginning of the 1960s, Dan Tolkowsky, who left the military after commanding the Israeli Air Force, joined Discount. Tolkowsky became instrumental in moving the discount group into high-technology investment. In 1961, he first met Uzia Galil, the founder of the Elron group, and throughout the 1960s and 1970s the Elron group and Discount became the main source of NTBFs in Israel. Elron, Elbit, and Elscient, all of which later managed an IPO on NASDAQ, were created by Galil with Tolkowsky, as the manager of Discount Investment, becoming their chairperson.

It is at this critical period of the birth of the Israeli high-technology industry that we see again the importance of Israel's academic infrastructure, Galil started his forays into the private market from the Technion, and recruited Suhami, Elscient's co-founder, while he was still a Ph.D. student at the Technion. Indeed, Elscient's first medical imaging products, on the basis of which it became the first Israeli company to be listed on the NASDAQ, were related to Suhami's work at the Technion.

Tolkowsky was also crucial at another critical juncture for the Israeli IT industry. By the end of the 1960s, after doing some business with the Rockefeller family's venture capital arm, he had realized the Israeli industry's need for experienced VCs with larger funds than Discount could muster. In 197, Tolkowsky decided to fly to the US to try to interest the then still young VC industry in investing in Israel. Knowing that on merit alone he would have limited chances, he decided to approach Arthur Rock, who was not

only one of Silicon Valley's most famous VCs (Rock was crucial in securing the financing for Fairchild Semiconductors and Intel, and later became involved in Apple, to name just three), but, even more importantly for Tolkowsky, was Jewish. Rock was unwilling to invest in anything that was not in Silicon Valley. However, he did introduce Tolkowsky to the other famous Jewish VC of the time, Fred Adler of New York (Adler was involved in Applied Materials and Data Systems at the time). Adler still remembers Rock's phone call:

> I got a phone call from Arthur about Dan Tolkowsky. He told me that Dan is seeking someone to invest in Israel. He then told me about Dan and his background: a fighter for the British RAF in WWII who became the commander of the Israeli Air Force. You must remember it was only three years after the 1967 war and I must admit that it got me so interested in the man himself that I wanted to meet him just because of that. (Interview with Fred Adler 9/28/2000)

Adler visited Israel and became involved first with Elscient. Realizing the futility of his efforts to raise VC for the company, Adler decided to jump-start the whole process by bypassing the VC stage altogether and raising money through an IPO. Adler assumed that after several IPOs had been successful the Israeli industry would look more inviting to American investors and the VC problem would be solved. Little did he know at the time that this process would take more than two decades.[23] Nonetheless, those activities started the strong connection of the Israeli industry and the American financial markets, a connection that the Israeli state later developed.

Another critical point was reached in 1968. Following the sudden French military embargo, the state channeled large investments and R&D power into military high-technology efforts. Similar changes followed in regard to the civilian R&D industrial policy. Israel's first committee on science and technology policy for industry – the

[23] To verify this account, interviews were conducted with Dan Tolkowsky 6/7/2000 and 8/10/2000, Uzia Galil 8/9/2000, and Fred Adler, 9/28/2000 see also Levav, Ibid, and Autler, Ibid.

Katchalski Committee – was convened. The Katchalski committee, headed by prominent academics, argued for the establishment of a Chief Scientist Office in each of the main government ministries. The most important of these was the Office of the Chief Scientist in the Ministry of Trade and Industry (henceforth: OCS). The OCS defines its objective as fixing market failures in the area of civilian industrial R&D. Its main program was designed in a similar way to those of academic grant-giving foundations, and provided a flat 50% (in the form of conditional loans) of the cost for any approved industrial R&D project originating from private industry aimed at developing a new exportable product. The loan was to be repaid only if the R&D project ended with a profitable product.[24]

However, even with the best efforts of private financial and technological entrepreneurs like Tolkowsky, Galil, and Adler, coupled with the assistance of the OCS, the industry remained cash-starved. Moreover, until the 1980s the problem was not only one of capital starvation, but also a lack of willing entrepreneurs. This can be attested by the fact that the OCS had difficulties in distributing its annual budget. In its special 1975 policy document, the OCS identified this as an acute problem:

> It is evident that despite the opportunities described in this section on the one hand, and the massive government support on the other, too few new technology-intensive industries are being established… Clearly we have here *a problem of technological entrepreneurship*. Despite opportunities and massive government aid, there are not enough people willing to take the risk. To reach the ultimate goal of industrial R&D, i.e., new increased exports, *particular attention must be given to this phenomenon as well.* (OCS 1975)

In the 1990s the situation finally changed. In the first half of the 1990s, the OCS initiated four new programs: Inbal (1991) and Yozma (1992) were intended to spur the local VC industry; the Technological Incubation Program (1991) to spur very early stage

[24] For the OCS earlier definition of its own role as fixing market failure in civilian R&D see, (OCS 1975), and, OCS 1977. For an analysis of the OCS systems in its early years, the logic behind it, and effects of its industrial sector "neutrality," see Teubal 1983, and, Teubal 1997.

entrepreneurship; and the MAGNET (1994) program to induce university-industry large scale R&D cooperation. The success of these OCS programs and the demonstration effect of the successful wave of NASDAQ IPOs in the first half of the 1990s spurred an unprecedented wave of entrepreneurial activity in Israel. The annual rate of company formation reached 400 in 1990-2000, and the total number of start-up companies in Israel is estimated to have been between 3500 to 4000 in 2000.[25]

Despite the rapid growth and success of the Israeli IT industry, the particular development path cultivated by the state and the IT industry over the last three decades, with its extremely close connection to the US, has not been without problems. In the second half of the 1990s, more and more Israeli companies decided to incorporate themselves in the US and are now for legal, and more importantly for taxation, purposes treated as US companies with an Israeli subsidiary.[26] Moreover, as more and more successful companies realize that the US is their main market, they move more functions and activities to the US. In fact these companies are turning themselves into quasi-American MNCs with their main R&D labs in Israel.

Israel's economic history and the development of the ST industrial policies:

[25] Data on start-up activities and formation should be taken with a large dose of skepticism but the same figures are constantly presented by both state and industry association organizations; furthermore, with a growing amount of start-ups receiving finance either from established VC funds and the OCS, there is good reason to assume that these figures do not stray from the truth to a very large degree.

[26] For obvious reasons, accurate data on these new Israeli born US incorporated firms is hard to get, but according to most VCs interviewed, in the period after 1998 a turning point was reached with over 50% of companies incorporating in the US. With the current downturn in the fiscal markets and the reemergence of OCS grants as a critical source of capital, this trend had slightly truncated in 2001, see also Harmony 3/3/2002.

Israel's economic history can be divided into three periods. The first period is Israel's first 25 years, in which the very high growth rates achieved by the Jewish settlement after 1922 were sustained. Immediately after the 1948 war of independence, Israel found itself isolated in a region with vastly larger enemies unwilling to do business with it, and with huge waves of immigration of Jews fleeing or being expelled from Arab countries and of European Holocaust survivors. These waves doubled Israel's population by 1954 and tripled it by 1963. In 1948 Israel had had one of the most highly educated workforces in the world, and while the waves of immigrants lowered the average level of education, the institutional underpinning of Israel's education system and its research-oriented tertiary education system was already well established and enabled Israel to quickly upgrade its workforce. From 1948 to 1973 Israel enjoyed almost uninterrupted rapid growth with an annual growth rate of 9%, and with GDP increasing tenfold since independence. This remarkable economic feat was achieved even as the state, led by the socialist labor party, was firmly committed to full employment.[27]

After the war of 1973 Israel suffered multiple economic crises. Economic growth was almost halted, the balance of payment deficit rose in alarming proportion, and inflation rapidly rose to over 400% annually. Moreover, by 1983 all of Israel's major banks confessed to participating in a scheme in which they ran their own shares in the Tel-Aviv Stock Exchange. This scheme became unsustainable and forced the government to nationalize these banks in order to save Israel's banking system from going bankrupt. In the period 1977 to 1985, the first political transfer of power intensified the economic crisis. The right wing Likud won the 1977 elections, implemented a series of untenable fiscal expansionary policies and eliminated barriers on capital transfer and exchange,

[27] For a collection of articles that analyze the growth of the Israeli economy, see (Ben-Porath 1986).

while continuing the pledge for full-employment. In 1985, a rainbow coalition government led a stringent stability plan. The plan succeeded in some areas: inflation was cut to a more manageable rate and continued to stabilize throughout the 1990s, and the GDP growth rate picked up from a low of 1.9% to a more reasonable rate.[28] However, since the end of the 1980s, unemployment has become a problem, especially in the periphery.

Starting in the 1980s and continuing at a faster rate in the 1990s, another transformation had become apparent, with the high-tech industry quickly growing, while the traditional and mixed industries and agriculture lost ground. Already by 1988, 59% of Israel's industrial exports were high-tech products, and by 1998 over 71% of Israel's industrial exports were high-tech. In 2000, the IT industry alone accounted for over 70% of GDP growth.[29] In addition, Israel's corporatist wage agreement regime was crumbling, with labor-union membership in rapid decline and the socialist ideology in fast retreat.[30]

At a more micro-level, Israel's industrial policy can be broadly divided into four main periods. In the first period, from 1948 to 1966, the state followed a protectionist economic policy coupled with an interventionist industrial policy in an attempt to secure three goals: security and regional policy, industrial development, and the building of a private-ownership-based economy. The huge waves of immigration were channeled to newly developed cities, which were located according to a security-based logic of Jewish population distribution throughout the country, rather than on a purely economic basis. The state anchored these new cities around privately owned, government-subsidized,

[28] For more about the causes of the crisis and the stabilization program, see an article written by the chairman of Israel's central bank at the time, Bruno 1989.
[29] See CBS 2001.
[30] For more about the history of neo-corporatism in Israel, see Shalev 1992, and Grinberg 1991.

large-scale plants. Textiles was one industry in particular that was the focus of this state industrial planning, but parts of the defense industry complex and various other industries were also enlisted in support of these aims. The state, led by the socialist party until 1977, had also used (surprisingly to some) its considerable power to ensure that private ownership of the forces of production became the predominant ownership form in a successful effort to create a vibrant capitalist economy in Israel.[31] The result of these policies was a quasi-private, large-scale-plant-based industrial sector, which was deeply dependent on government subsidizes and help, and actively lobbied for them.

From 1965 to1967 Israel suffered its first recession, which ended with the 1967 war. The end of the war was critical to Israel's S&T industrial policy, thanks to the unexpected hero of the Israeli IT industry: France's President Charles de Gaulle. Today, after three decades of close alliance with the USA, only a few remember that in the first two decades of its independence, Israel's main ally was France. Israel bought almost all of its military equipment, including critical systems like fighter-jets and ships, from France, and Israeli engineers worked closely with French teams on the modification of and specific systems R&D for various weapon platforms.[32]

In 1967 de Gaulle declared an immediate military embargo on Israel. That decision resulted in Israel's inability to buy critical weapon systems off the shelf anywhere in the world.[33] The immediate reaction of the Israeli state was to dedicate large sums of money and R&D power into military high-technology efforts. It was decided that

[31] An interesting study, that fellows the "developmental state" literature, on the first 25 years of industrialization in Israel is David Levi-Faur's (Levi-Faur 2001).
[32] Israel and France conducted many co-development research projects. France and Israel were also crucial for each other's nuclear programs, with France licensing the technology developed at the Weitzmann Institute for the production of heavy water and helping Israel, in return, to build its nuclear reactor.
[33] The alliance with the US did not commence until after the 1973 war, and even to this day the US does not allow Israel access to a number of crucial technologies.

Israel should not be completely dependent on a foreign power for military platforms. Starting in 1967, Israel's military R&D targets changed from developing niche weapons systems, the most sophisticated of which were radar-guided rockets, to developing its own weapons platforms such as tanks, fighter-jets, and ships.

With the decision in the 1980s to stop the development of the latest fighter-jet (the "Lavi"), this strategy was officially abandoned. However, Israeli companies still develop tanks, coastguard ships, and precision-guided rocket systems of all kinds (in addition to niche products and communication-related systems). Moreover, the amount of large-scale-system-integrated multi-disciplinary R&D knowledge, capabilities, and, more importantly, management experience gained by the Israeli high-technology industry is almost incomparable to any state of the same size.

At least as important as the complete overhaul of military R&D that Charles de Gaulle spurred were the related changes in industrial policy that occurred in 1968. Analyzing the recession of 1965-67, the state realized that growing exports necessitated a change in Israel's industrial policy. That realization, coupled with the renewed interest in and success of military R&D, led Prime Minister Levi Eshkol to ask his old friend and one of the key people behind the creation of RAFAEL, Professor Ephraim Katchalski-Katzir, to head a special committee on governmental founded civilian industrial R&D.[34] The Katchalski committee argued that Israel's industrial future lay in its ability to use its extensive scientific research capabilities to create s*cience-based* industries (Katchalski 1968).

[34] Ephraim Katchalski-Katzir was later elected to serve as the President of Israel, the symbolic head of state. It is interesting to see that at the time science was so highly regarded in Israel that all the first four Presidents of Israel were renowned scientists or scholars.

In order to secure this goal, the committee recommended the establishment of the Chief Scientist Offices in the main government ministries, the key one of which was in the Ministry of Trade and Industry. The Office of the Chief Scientist in the Ministry of Trade and Industry was formally established in 1968, but started full-scale operation only in 1973. True to their scientific socialization the committee members envisioned the role of the OCS in similar terms to that of an academic grant giving foundation – spurring research by supplying the needed funds. Influenced by Kenneth Arrow's seminal paper the OCS's objectives were defined as fixing market failures in the area of civilian industrial R&D(Arrow 1962). The OCS provided, in the form of conditional repayable loans, a flat 50% of the cost of any industrial R&D project aimed at developing a new exportable product. These grants were distributed impartially without regard to specific industrial sectors, the main logic behind the OCS being to fix market failures in R&D investment with the explicit assumption that private entrepreneurs would know best the most profitable markets in which to innovate (Teubal 1983).

Moreover, both the committee and later the OCS itself recognized that Israel was already well endowed with academic R&D capabilities that had been successfully diffused to the defense sector. Accordingly they built an S&T policy aimed at diffusion of R&D capabilities and the spurring of economic capabilities on top of them (Carlsson and Eliason 1994; Loasby 1998). In the 1970s OCS's grants helped projects as diverse as bio-medical electronics, computer development, geothermal power plants, and pre-set printing.

Consequently, at the same time that the 1973-1985 economic crisis was destroying Israel's old political economy and weakening the traditional and mixed

industrial branches as well as the established financial system, the new focus on science-based industrial development and the major investments in the defense industries were slowly building the foundations of the new IT industry. In 1972, the first Israeli IT firm listed on the NASDAQ, but by the end of the economic crisis in 1985 an IPO on NASDAQ was already a legitimate and well-trodden path for the more successful Israeli high-technology companies. However, the IT sector did not pass through the economic crisis unscathed, and with the crushing of the banking system both the Elron group and Scitex were faced with their biggest crises to date. Nevertheless, by that time they were no longer the only IT corporations in Israel.

The OCS started its activity in earnest only in 1973 after Yaakov Itzhak (Yatza) was recruited from a similar role in the IDF. After Yatza joined the OCS, the agency quickly developed its activities, taking a very proactive role to the point where the OCS's main problem in that period was the lack of willing entrepreneurs. Another important decision at the time gave the OCS the ability to grant an "approved plant" status to NTBFs, which granted them all the economic incentives and aid given under the 1959 Law for the Encouragement of Capital Investments, the same law used to grant aid to plants in the newly constructed peripheral cities. That linkage became more important in later years when Intel, National Semiconductor, and Tower applied for aid under its provisions when constructing silicon chip fabrication plants.[35]

Following the 1973 war and President Nixon's visit to Israel, the Bi-national Industrial R&D foundation (BIRD) was approved in 1975, put under the jurisdiction of the OCS, and started working on fostering and financing cooperation between Israeli and

[35] While probably critical in securing the construction of the fabs in Israel, the overall economic effects of the capital investment law were probably negative even in the 1990s, see Bregman et al. 1998.

US companies. The basis of its mode of operation was a strategy of organizational and industrial development that saw a clear division of labor between Israel and the US. BIRD only funded projects in which the R&D was done in Israel and the marketing in the US. Like the OCS, BIRD did not start its operation until its second executive director, Ed Mlavsky, arrived. Within a short time, BIRD became crucial not only in sponsoring and helping Israeli NTBFs, but as an organization that ensured these NTBFs a critical window into what became their main market, the US. BIRD had also become crucial in the latter part of this period and throughout the 1980s and 1990s in the enticement of American MNCs to open R&D subsidiaries in Israel.

The third period started with the approval of the R&D law in 1984 and the recognition of software as an industrial branch in 1985. Until that time the OCS, not anchored in law, fought chronic budgetary battles, and also, following political lobbying by Elscient that ended with a tax-sanction law (aptly nicknamed the Elscient law), question marks over the OCS's capture by industry tarnished its image. The period from 1984 until the beginning of the 1990s was the reconstruction period of the institutional basis of Israel's political economy. With a few rare exceptions the old centralized traditional and mixed branches of industry quickly lost ground, the ideology of full employment was no longer held to, and the state-owned defense industry companies started their decline with the cancellation of the Lavi project and the realization that the state was unable to continue to finance them to such a high degree.[36] However, under the new R&D law the OCS quickly expanded its activities together with BIRD's; the Elscient law was revoked in 1985; and, sanctioned by the R&D law, the OCS regained its

[36] The transformation was not that apparent at the time and many commentators thought it had failed; for example, see Teubal 1993.

independence and public image as a professional agency. By that time, private IT entrepreneurs were becoming more common, active and successful. In addition, the second stage of the IT industry started with the first international success of Israeli software product companies.

The most recent period began in 1989. The democratization and break up of the USSR started the last large immigration wave into Israel. The approach to this wave was dramatically different from the earlier waves of immigration. This wave was seen as bringing with it the best and the brightest technologically-educated workforce from the USSR. Together with the thousands of engineers who had been made redundant by the defense industry, the question of tapping this body of knowledge sprang to the top of the political agenda. In addition, the Israeli government secured the United States' help in raising $10 billion in bonds to finance the settlement of the immigrants (20% of the total population in less than one decade). Thus, with the old political-economic institutional system of Israel crumbling, the political and bureaucratic apparatus of the Israeli state, knowing it had to act and having sufficient finance, was very open to new initiatives led by the OCS.[37]

Starting in 1991, the OCS, led by Yigal Erlich, initiated and implemented four new programs. Interestingly, while the last three programs, The Technological Incubators, Yozma, and Magnet, only started operation between 1992 and 1995, they were all planned and approved in 1991, the year that can be seen as the high point of the latest political window of opportunity.[38] In 1991, two new programs started operations, each aimed at solving a perceived market failure at a different development-stage of

[37] For more about the present R&D policy and schemes, see Trajtenberg 2000.
[38] Interview with Yigal Erlich 8/21/2000.

NTBFs. The Inbal program was the first serious government attempt to induce the creation of a private VC industry in Israel, long viewed as a critical missing link that would enable Israeli NTBFs to succeed in the market after the end of their product development phase.

Until 1991 only two VC institutions were present in Israel: Tolkowsky and Adler's Atena VC fund, a limited partnership fund established in 1985 based on the American model, and Star, a private equity fund established in 1989 that became a Yozma fund after 1993. The Inbal program was an attempt to foster publicly-traded VC companies by creating a government insurance company ("Inbal") that guaranteed new VC funds traded on the Tel Aviv Stock Exchange a minimum value, calculated as 70% of the value of the initial public offering, and issued certain restrictions on the investments of insured funds. Four funds were initially established, but no follow-up activity was spurred and the funds' valuation on the stock exchange tended to be low. The funds felt that they deal with excessive bureaucracy and left the program. Today all the funds are under the management of one holding company – Green Technology Holding (Avnimelech and Teubal 2002).

In the same year, 1991, the OCS also initiated the Technological Incubators Program. Initially the program was presented as a solution to two problems: first, the inexperience and inability of many scientific entrepreneurs to become successful commercial entrepreneurs and find very early stage financing for their ideas; and second, the difficulty of many of the technologically skilled new Russian immigrants to find jobs and successfully integrate into a capitalist market economy. A network of technological incubators was opened to help entrepreneurs in the very early stages of transforming an

immature idea into a commercial reality, giving them most of the financing and a large amount of professional business and management help. The logic behind the program has been, first, that Israel's scientific community produces far larger numbers of commercially viable ideas than get financed; and second, that there is a need for a program that will give the missing incentives and financial support for researchers who lack the business experience to become entrepreneurs. A recent study found that 84% of incubation's company founders have a graduate degree, with 63% having a Ph.D. (Shefer and Frenkel 2002).

The goal of the program has been that after two years, companies graduating from it would be mature enough to secure private VC financing. In similar fashion to the other OCS programs, incubation proposals had to come from the market. Teams consisting of academic institutes, municipalities, and businesses that passed through a quality assurance process were given management over nearly evenly geographically distributed incubators throughout Israel. The incubators need to find and recruit entrepreneurs, test their business plans, and then send these as applications to the OCS. Each accepted application is granted up to 85% of financing (as of 2002, around $400,000) for the first two years of operation. By the end of 2000, 24 incubators were in operation and 883 companies had been part of the program. Of these, 240 were still in the incubation centers and 643 had graduated. Of those that graduated, 53% have continued operations and 47% have been closed down. The total private VC financing that the graduating companies managed to secure was in excess of $525 million, with the government funds standing at $30 million annually. In addition, one company, Compugen, is already publicly listed on the NASDAQ and is considered to be one of the leaders in its niche market, and a few

more were bought by MNCs. It is also reasonable to assume that more IPOs and mergers will follow, since ten or more incubator companies have secured major investment rounds (more then $10 million) from leading American investment banks and underwriters.

Until 2001 (when specialized incubators programs were approved, if none, yet, started operation), the incubators operated in a similar fashion to the OCS' other programs. While some of the incubators became more specialized in time, overall the technological incubators network did not pick any sectors, and R&D projects from all branches of industry were admitted. As a result, the distribution of projects by industry through 2000 was as follows: electronics and communication 11%, software 11%, medical 18%, chemistry and materials 20%, biotechnology 20%, and others 23%.[39] Starting in 2003, a few established VC funds opted to buy and manage a few incubators.

Two of the most important impacts of the program have yet to be considered and tested properly. First is the major impact that the program has had on changing the preferences of technologically and scientifically educated personnel to willingly become entrepreneurs, an effect that might prove to have been catalytic. Second, as the present technology crisis shows, the program is important in ensuring a minimum NTBF formation rate, which is immune to the volatile behavior of the VC industry in regard to the amount of investment and the herd mentality and fashion-like behavior of VCs in their sectoral investment criteria. For a state like Israel that is economically dependent on the high-technology sector, securing this baseline is of critical priority.

[39] Interview with Rina Pridor (2/8/2000), Trajtenberg, Ibid, and the incubation program web site http://www.incubators.org.il.

The technological incubation program has been the target of attacks from both ends of the political spectrum. Some argue that it is a too-costly program of job creation and that the state has poured too many resources into it without any apparent successes. Others argue that the way in which the program is constructed grants too little financing to its companies and forces them, long before they are ready, into a vicious cycle of raising capital, saddled with the stigma of an "incubation" i.e., not fully mature company. However, while the incubation program is far from being an unqualified success, a few more years must pass before it can be determined whether the program has accomplished what it set out to do.[40]

In the same years that the OCS was busily developing and implementing its new programs, new developments in the private sector were changing the IT industrial landscape in Israel. Before 1990 there had been a total of ten IPOs of Israeli firms on NASDAQ. In 1991 alone three companies went through IPOs, and in 1992 there were another nine. Moreover, unlike the low valuation IPOs of the past, some of these IPOs resulted in a large enough market capitalization to provide a respectable exit for an American VC at the time. Also in 1991 the first pure software companies had gone public on NASDAQ. In 1991-1992 it became apparent that the Israeli IT industry had passed into a larger and more mature phase of operation, with an even closer connection with the American financial markets.

In 1992, learning from the failure of Inbal, the OCS initiated another program aimed at inducing the creation of a vibrant VC industry in Israel – Yozma. This time, and in almost complete opposition to its behavior in the past, the OCS decided that the

[40] There are two recent reports on the incubation program, one was conducted independently (Shefer and Frenkel 2002) and the other done under the auspice of the OCS (Economics 2001).

necessary skills and knowledge did not exist in Israel, and that in order to succeed an Israeli VC industry would need strong networks with foreign financial markets, and not with the Tel Aviv Stock exchange. As a result, Yozma was created as a government VC fund of $100 million that had two functions. The first was to invest $8 million in a series of ten private limited partnership venture funds, which would be 40% or less of the total capital – the rest to be provided by the other private limited partners. In order to obtain this government financing the funds had to secure investment and partnership from at least one established foreign financial institution and from at least one local one. Each fund was also offered a call option on the government share at cost plus interest for five years. Thus, if the fund management thought that its investments were going to succeed it could buy the government out cheaply. Yozma invested $80 million in ten funds: five were established in 1993, one in 1994, two in 1995, and one in 1996, and all but one opted to use the call option. Second, as well as investing in those funds Yozma also started its own VC fund, Yozma I, with $20 million under management with Yigal Erlich, who had left the OCS to head the Yozma program, as its CEO. Private businessmen later bought the Yozma fund.[41]

Unlike Inbal, Yozma was highly successful and became a model for VC-aimed policy worldwide. The establishment of the 11 Yozma funds, the growing success of Israeli companies on NASDAQ, the fact that the Israeli landscape at the time had many high quality NTBFs looking for capital, and the coincidence with the start of a period of rapid growth in demand for IT and the related financial boom, resulted in excellent returns for the Yozma funds, and a rapid investment of capital into the Israeli VC industry (see graph 5). Today the Israeli VC industry consists of over 70 funds, with

[41] Interview with Yigal Erlich 8/21/2000.

many of the top US and global funds starting operations in Israel and with total capital under management of approximately $5 billion. Moreover, the success of Israeli companies in the US in the 1990s transformed the institutional setting and for the last few years many Israeli companies have raised capital directly from established foreign VCs and financial institutions in their later (and sometime even in their earlier) development stages.[42]

Add Graph 6 VC in Israel about here

The last initiative designed by the OCS in 1991, MAGNET, also started operations in 1992, systematized its activities in 1994, and added another smaller-project sponsorship path in 2001. Unlike the other OCS programs, MAGNET, which stands for Generic Non-Competitive R&D, aims to solve two problems relating to the later stages of development and maintenance of the long-term competitive advantage of Israeli NTBFs. First is the fact that in Israel a large number of companies work in the same technological space, all of them too small to be able to compete on the basis of, or advance, cutting edge *infra-structural* research activities that are crucial for their ability to sustain competitive advantage against the bigger MNCs. Second is the continuing underutilization and under-diffusion of Israeli academic research. Like the other OCS programs, MAGNET grants aid to programs initiated by private industry. However, as MAGNET aims to create a consortium to develop generic technologies, a MAGNET consortium is created for a period of up to three years and all IP outputs are shared among the consortium members, who also agree to license this IP to local companies at a cost that does not reflect monopoly status. A consortium, consisting of at least a few companies and one research/academic institution, applies in a competitive fashion to

[42] For more about the development of the VC industry in Israel, see Avnimelech and Teubal 2002.

MAGNET, and if approved, is granted financing to the level of 66% of its costs for the agreed period. MAGNET financial aid is given in the form of grants, with no need to repay. A parallel process exists for consortia of users with the aim of distribution and implementation of generic technology.

Over the years many research consortia in highly heterogeneous technological fields have been formed. Some examples are: ground stations for satellite communication, magnesium technologies, multimedia on-line service, DNA markers, advanced electronic packaging, and ultra-concentrated solar energy applications. The demand of industry and academia for research consortia funds has been overwhelming and, as early as 1996, MAGNET became the second largest program of the OCS. In the 2001 fiscal year, existing MAGNET research consortia received $64 million from the OCS. The users' organization program has been less successful, with only one serious user organization in advanced technologies in electronics ever making progress.

During this period the OCS's budgetary growth was quickly transformed into extensive investment in the industry. Moreover, the success of projects financed through it increased the amounts the OCS was able to channel to the industry, creating a virtuous cycle throughout the 1990s.

Add Table 5 OCS annual budget and activities about here

Interestingly enough, while the wave of immigration from the former USSR undoubtedly created the pretext with which the OCS was able to secure the funds and the political agreement needed to start these four programs, the Russian immigrants themselves have not, thus far, become successful technological entrepreneurs, and seem to play the important but more minor role of providing highly-skilled labor. A

preliminary analysis of an original dataset of the career paths of founders of Israeli IT NTBFs that went public on foreign exchanges has yet to find one new immigrant from the former USSR among the 151 founders on which comprehensive data was acquired.[43] This finding is strengthened when we analyze the data of the Central Bureau of Statistics on the distribution of new immigrants in the IT labor market. Looking at three sub-categories of the high-tech labor-markets from 1995 to 1999, the total number of new immigrants workers in *industry* (i.e., more routine and maintenance jobs) rose at a higher rate than that of Israelis. In *telecommunications* there was a slight increase in the number of new immigrants, but the number of Israelis grew faster and 95% of the workers were Israelis. In the most highly-skilled labor market category, *computerization and R&D* (i.e., high level R&D and programming jobs), however, the total number of new immigrants went down, while the total number of Israelis went up sharply (over 25% growth).[44]

In summary, the industrial development agencies of the Israeli state proved very able and flexible in advancing the overarching goals of creating science-based industry in Israel and advancing NTBFs as the cornerstone of this industry. At many critical points the state either spurred the creation of local industry, initiated catalytic programs that induced institutional transformation and fast growth, or created the necessary service industry. Moreover, the OCS was also crucial in sustaining and enhancing the R&D capabilities and successes of the Israeli IT industry. *However, these programs have all been based on the assumption that the necessary R&D skills are already abundant in*

[43] The founder of one medical equipment company, Medinol, on which comprehensive data on the founders has not yet been added, is a new immigrant. However, the story of how the company was founded by a very successful and experienced Israeli-born entrepreneur who befriended Medinol's new-immigrant technological founder on the beach, points to the exceptional circumstances of its founding and to the difficulties that immigrants from the former USSR has in establishing successful NTBFs in a capitalist economy.

[44] See, Abouganem and Feldman 2002. Pp. 27-28.

Israel and the role of the state is to spur more activity and channel it toward civilian industrial R&D. Thus, one could argue that the history of the development of the IT industry in Israel is one of successful state-led capability diffusion, rather than state-led capability creation. In Israel both state and industry have managed to perform the intricate dance of development as partners that help and assist each other, not as competitors for control and jurisdiction. Thus, while the state proved critical at many points, many of the initiatives, for example, the beginning of IT entrepreneurship, the first attempts at creating VC funds, and the strong ties with US industry and capital markets, were first taken by entrepreneurs in the private market and only then adhered to and enhanced by the state.

Conclusion

This paper argues that Israel's main competitive advantage has been Israel's R&D. These capabilities are the core of the Israeli IT industry's success. The source of these capabilities has been the strong academic research apparatus. After their successful usage by the defense industry these capabilities were diffused by various state polices throughout the innovation system. The paper also argues that the IT industry evolved in two phases, first successfully developing the hardware sector, and only then developing the software sector. Finally, this paper argues that it was the conscious aim of the Israeli state to develop an industry with these exact capabilities, and shows that at critical points the state, through the OCS, started catalytic programs that spurred private technological entrepreneurship.

The Israeli IT industry owes its beginning to state efforts that started in 1968. The Israeli state, building on strong academic institutions that already possessed strong research capabilities, on a nascent if growing science-based industry mostly amassed around the Elron group and Discount investment, on a large high-technology-oriented defense industry, and faced with a critical security threat, developed a consensus view of science-based industry as a solution for Israel's economic future. The concept around which the Israeli industry developed viewed industrial R&D activities as the focal point of any economic growth, with the state role one of fixing broadly-defined market failures associated with R&D in a proactive way.

This notion and the specific way it was institutionalized have had a pronounced impact on business development in Israel. Due to the fact that capital for business development was almost impossible to secure, the importance of the financial options offered by the OCS and later by BIRD cannot be underestimated. From the end of the 1960s to the 1990s, the most prominent opportunity for any Israeli wishing to become an entrepreneur was to develop a concept for technology-based products and build a company around it. Thus, for over thirty years entrepreneurs-to-be were prompted to think and see their businesses as new-technology-product-development-company. The OCS and its various programs spurred the development and growth of the Israeli IT industry at the same time that they also primed and trained these companies to view the R&D product development process as the heart of their activities. In addition, following the French embargo, through the establishment of the IPO on NASDAQ path by Elscient, strengthened by the activities of the BIRD foundation, and cemented in the development of the 1990s, Israel's IT industry became intimately connected with the American market.

If these arguments are correct then there are a few theoretical and empirical issues that need to be dealt with. First, there is the issue of our ability to generalize lessons from the Israeli case. Since many commentators have looked to the Israeli case as one of success to be emulated, it is important to note that Israel's S&T industrial polices were all built around the notion of diffusing already-existing top notch domestic R&D and technological capabilities. Thus, while many states, both developed and developing, can learn from Israel how to diffuse capabilities throughout the innovation system, it might be worthwhile for those states that do not already possess them to look for other models in regard to the question of R&D capability building and foreign technology absorption.

Second, there are some empirical issues that relate to the future development of Israel's IT industry. First, at this point the intimate connection of the Israeli industry to the US, undoubtedly one of the main causes of the tremendous growth of the IT industry in Israel, poses new and growing problems for policy makers and Israeli society alike. With the growing success of Israeli firms in the United States and the rush of American capital to the Israeli IT industry in the 1990s, the pull of the American market on Israeli NTBFs became more pronounced. With not only their customers, but also a growing share of their investors and shareholders being American, and with the Israeli market becoming less important, more and more Israeli companies feel the need to become as American as they can.

This development is not only apparent in the behavior of the Israeli firms that are pulled into the American market, but also with the growing importance of American MNCs in Israel and their ability to capture a large percentage of the innovative capacity of Israel. If we return to our patent data it comes as no surprise that American MNCs are

the leading patent issuers in Israel. The acquisition of Indigo N.V. by HP only shows that this trend continues even under more adverse market conditions. This fact makes the question of the ownership, and more importantly of who enjoys the fruits of the growth of the IT industry, even more keenly felt.

Second, if the analysis that this paper presented is correct, and Israel's main competitive advantage is its high-quality R&D capabilities, a much more serious question mark hangs over the future of the Israeli IT industry. Israel's education system, ranging from K-12 through the higher education institutions, faces a prolonged crisis and deteriorating quality and standards in the teaching of math and science.[45] Ironically, it might be that the future of Israel's IT industry is in danger due to a double jeopardy caused by its own success. The growing success of the IT sector has not only turned public attention away from the growing problems of Israel's education system but has also aggravated them by tempting many good researchers to leave the academy. All of these developments have been happening at a time of flux in the Israeli higher education system, with the establishment of regional colleges in the 1990s and growing question marks over the long-term commitment of the Israeli government to building the academic R&D infrastructure and sponsoring university level research.[46]

Thus, the IT industry's development path, with its reliance on the strong infrastructure of research universities, might ultimately be undermined by its own

[45] Reliable longitudinal international comparative studies of elementary and secondary student achievements are notoriously rare, however, The TIMSS study of 1995 and the Repeat-TIMSSS of 1999, the biggest over international studies conducted, might give us a glimpse. In both the Israeli students scored lower then average in math and science and their scoring had one of the sharpest decrease from 1995 to 1998 (Beaton et al. 1996; Martin et al. 2000; Mullis et al. 1997; Mullis et al. 2000).

[46] According to Israel's Central Bureau of Statistics the level of state support for universities in the 1990s moved around 51% to 57%, the OECD average for 1997 was 82%, a gap of more then 20%. In addition, while the OECD average of the state expenditure on 3rd level education out of total expenditures was 2.7% in Israel the average stood at 2.2% (Bentur 2002; CBS 1999a; CBS 1999b; CBS 2000a; CBS 2000b).

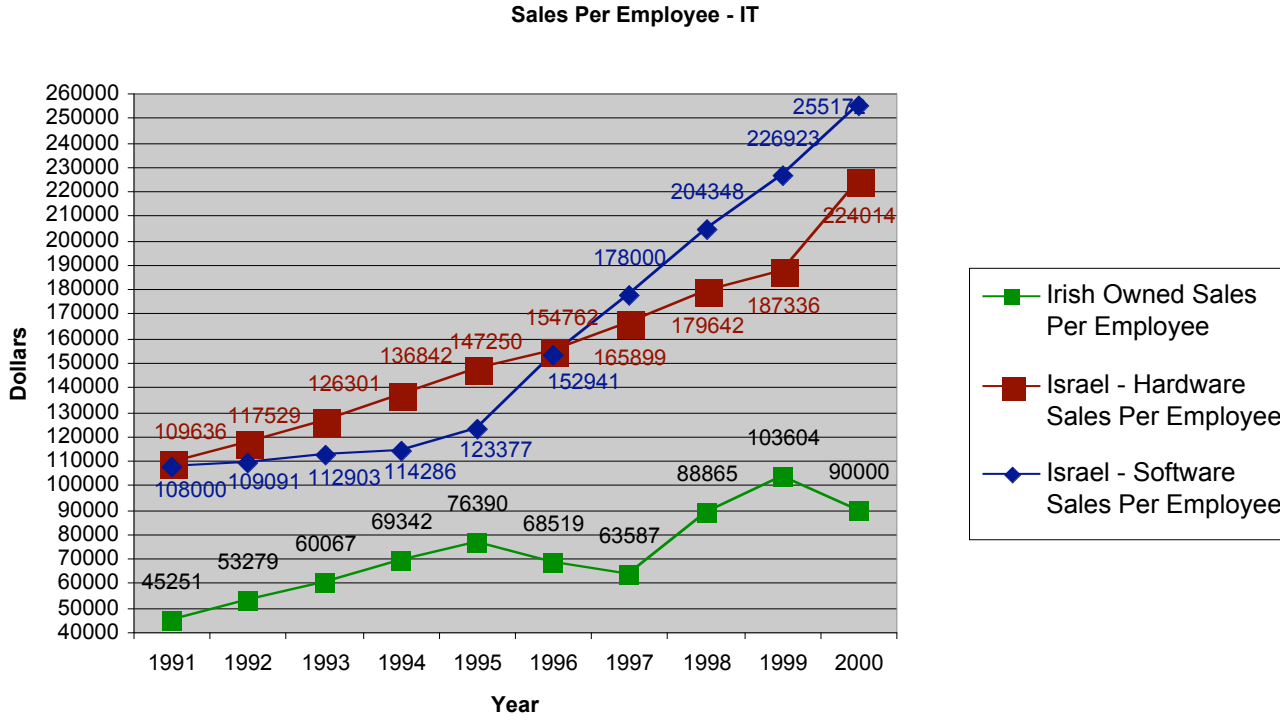
success. Moreover, the close connection with the American market this model has fostered, although leading the IT industry from success to success, might now prevent Israel's society from long-term enjoyment of this growth.

Appendix I – Tables and Graphs

Graph – 1

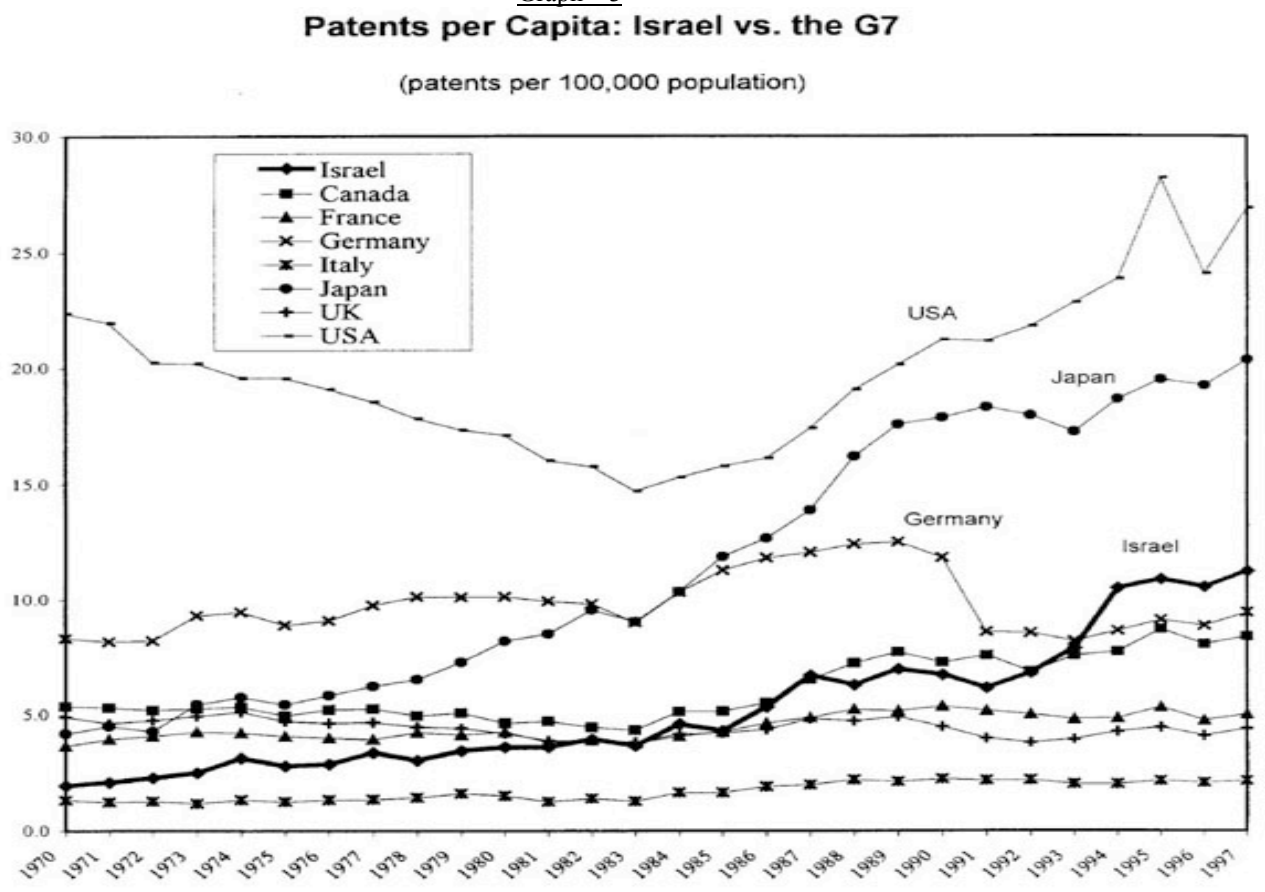
Source:(IAEI 2002; IASH 2002; NID 2002). Note: Until 1997 data in Ireland was collected every two years.

Graph - 2



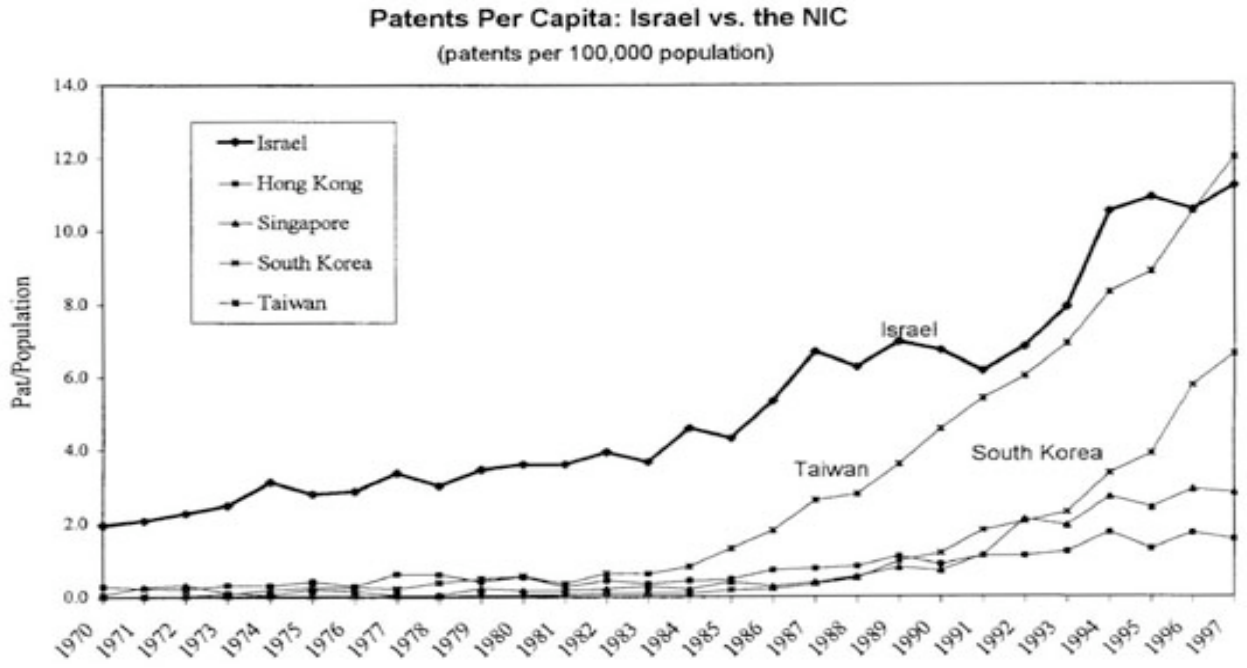
Source: (IAEI 2002; IASH 2002; NID 2002). Note: Until 1997 data in Ireland was collected every two years.

Graph – 3



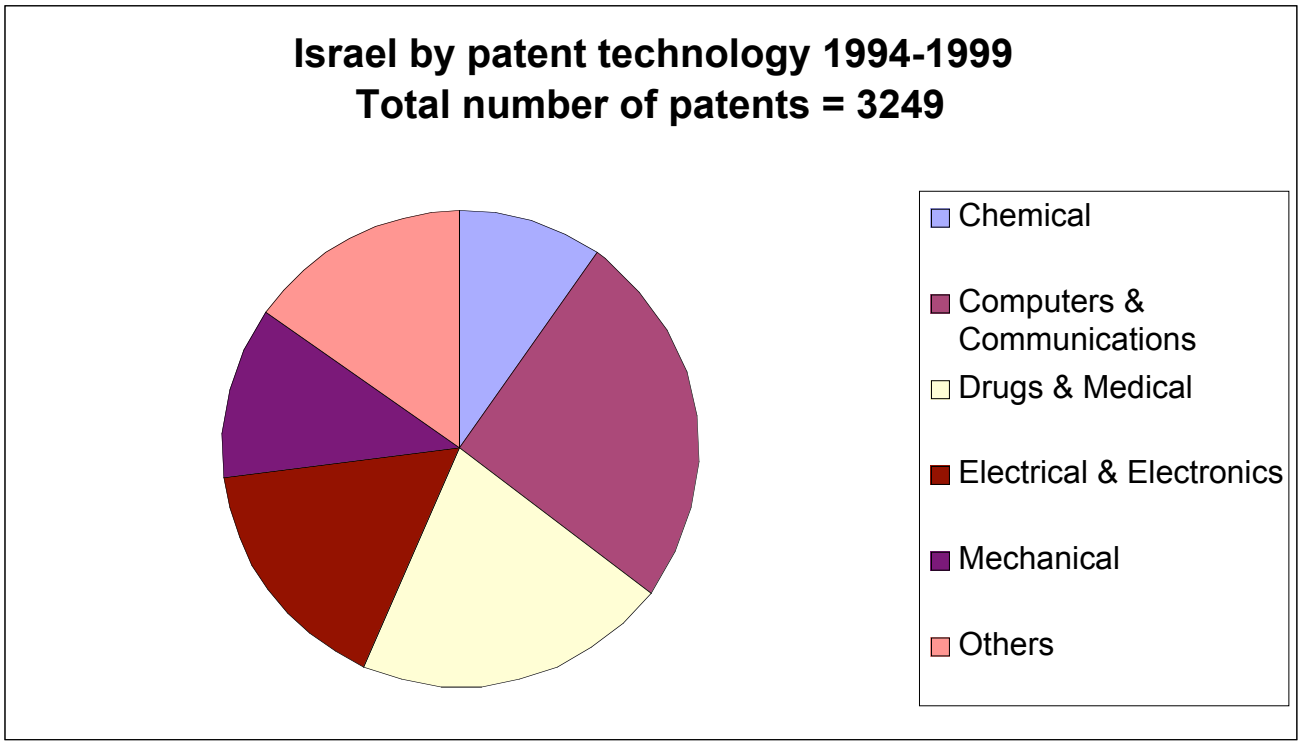
Source: (Trajtenberg 2001).

Graph 4



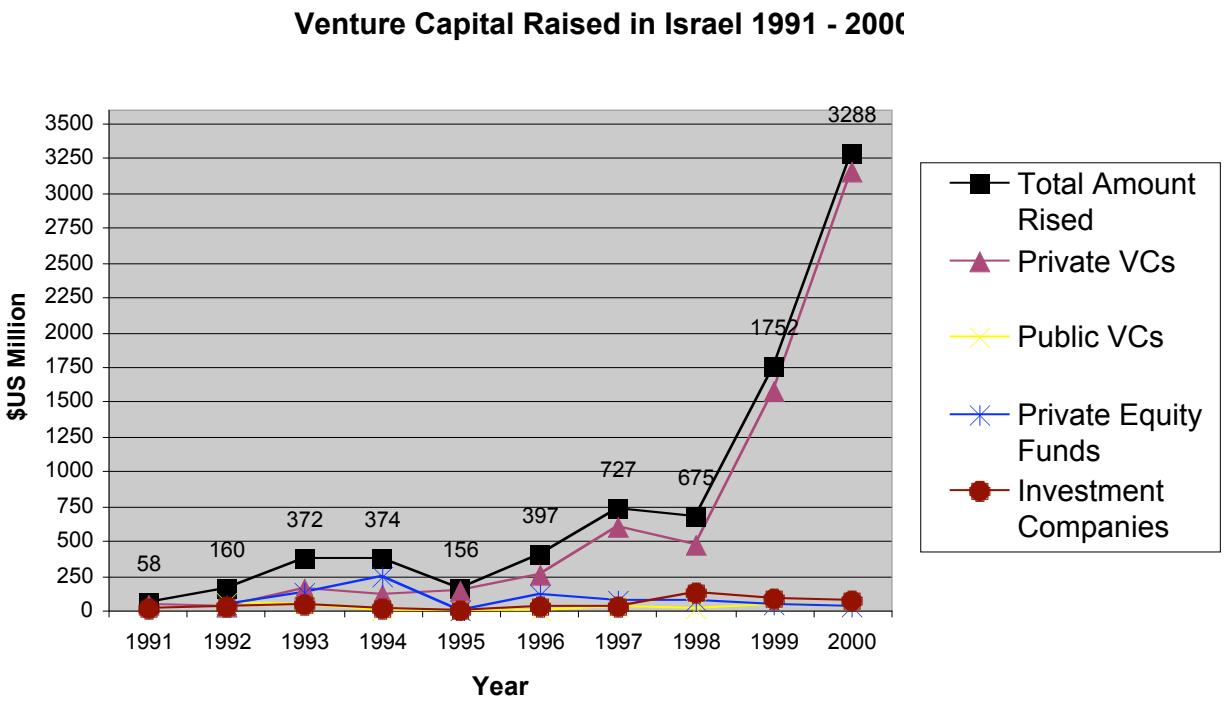
Source: (Trajtenberg 2001).

Graph – 5



Source: author's calculation on the NBER Patent Citation Data File, (Hall et al. 2001)

Graph – 6



Source: Source: Israel Venture Capital Association, (Avnimelech and Teubal 2002)

Table 1 – Software and Hardware Sales and Exports Ireland and Israel USD million

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Irish-owned SW exports	70	101	132	195	258	334	410	509	713	788
Irish-owned SW sales	172	221	270	356	441	513	585	822	1150	1269
Israel HW exports			330	485	734	1085	1750	2650	4000	6300
Israel HW sales	3618	3966	4610	5200	5890	6500	7200	8030	8580	12500
Israel SW exports	2283	2660	3200	3750	4300	4880	5700	6550	7130	11000
Israel SW sales	540	600	700	800	950	1300	1780	2350	2950	3700

Sources: (Arora and Athreye 2002; IAEI 2002; IASH 2002; NID 2002)
Note: Until 1997 data in Ireland was collected every two years.

Table 2 – Selected Countries ranking by scientific articles per GDP ratio (1997 figures)

Country	GDP (US $ Billion	Articles	Articles/GDP (billion)	Rank
Israel	96.7	6,556	67.8	1
Sweden	176.2	10,523	59.7	2
Switzerland	172.4	9,887	57.3	3
Finland	102.1	4,823	47.2	4
Denmark	122.5	5,430	44.3	5
New Zealand	63.4	2,737	43.2	6
Netherlands	343.9	13,724	39.9	7
Estonia	9.3	342	36.6	8
United Kingdom	1,242.00	45,231	36.4	9
Canada	658	23,560	35.8	10
Ireland	59.9	1,469	24.5	26
United States	8,083.00	176,141	21.8	28
Taiwan	308	5,512	17.9	34
South Korea	631.2	5,411	8.6	44
India	1,534.00	9,248	6	50

Source: (NSB 2000) table 6-57

Table 3 – Top patent issuing organization in India, Ireland, and Israel 1996-2001

Israel	**Organization Name**	**Total Patenting 1996-2001**
1	Yeda (Weitzmann Institute)	132
2	Motorola, Inc	126
3	Yissum (Hebrew University)	119
4	Intel Corporation	98
5	IBM	80
6	Ramot (Tel-Aviv University)	63
7	ISCAR	56
8	RAFAEL	48
9	National Semiconductors Corporation	46
10	ORMAT	40
11	Scitex	40
12	Biosence, Inc.	27
13	Indigo N.V. (bought by HP in 2002)	27
14	3Com (R&D center Spun-off as Atrica in 2001)	26
15	Bio-Technology General Corp.	26
Ireland	**Organization Name**	**Total Patenting 1996-2001**
1	Analog Devices	47
2	Elan Corporation (including Elan Medical)	20
3	Ave Connaught	11
4	Molex Inc.	11
5	3Com	10
6	Loctite (Ireland) Limited	8
7	Ericsson	7
8	IBM	6
9	Bausch & Lomb	5
10	Bourn, Inc.	5
11	Donnelly Corporation	5
12	Purtian-Bennett Corparation	5

Source: (TAF 2002)

Table 4 - Distribution of patents in top ten classes and number for selected countries (1996-2001)

	United State	Israel	India	Ireland
1	424 – Drug (19865)	424 – Drug (286)	424 – Drug (126)	424 – Drug (30)
2	435 – Chemistry: M. Biology (12316)	128 – Surgery (171)	532 – Organic compounds (120)	341 – Coded data generation (26)
3	520 – Synthetic resins – rubber (7781)	435 – Chemistry: M. Biology (137)	435 – Chemistry: M. Biology (34)	601 – Surgery: medicators and receptors (20)
4	438 Semiconductor device manufacturing: process (7604)	606 – Surgery: instruments (106)	520 – Synthetic resins – rubber (29)	435 – Chemistry: M. Biology (13)
5	128 – Surgery (7450)	370 – Multiplex communication (85)	502 – Catalyst, solid sorbent (20)	257 – Active solid-state devices (12)
6	532 – Organic compounds (7405)	340 – Communication: Electrical (70)	585 – Chemistry of hydrocarbon compounds (14)	439 – Electric connectors (12)
7	428 – Stock Material and Misc. Articles (6681)	382- Image analysis (69)	510 – Cleaning compositions for solid surfaces (11)	128 - Surgery (11)
8	128 – Surgery (5776)	532 – Organic compounds (65)	326 - Electronic digital logic circuitry (8)	222- Dispensing (11)
9	345 – Computer Graphic Processing (5366)	375 - Pulse or digital communication (62)	365 – Static information S&R (8)	327 – Misc. Active electric non-linear devices (10)
10	257 – Active solid-state devices (4914)	359 – Optics: systems and elements (including communication) (57)	327 – Misc. Active electric non-linear devices (7)	370 – Multiplex Communication (10)

Source: (TAF 2002)

Table 5 - OCS's Annual Budget 1988-1999 (in 2000 $USD million)

Year	R&D Grants	Paybacks	Magnet	Incubators	Paybacks as % of investment	Number of approved grants to IT firms
1988	120	8	-	-	6.7	
1989	125	10	-	-	8.0	
1990	136	14	-	-	10.3	380
1991	179	20	0.3	3.6	11.2	460
1992	199	25	4.7	16	12.6	458
1993	231	33	4.6	23	14.3	481
1994	316	42	10	28	13.3	605
1995	346	56	15	31	16.2	559
1996	348	79	36	30	22.7	556
1997	397	102	53	30	25.7	517
1998	400	117	61	30	29.3	505
1999	428	139	60	30	32.5	506

Source: OCS 2000. Note: Paybacks from each successful project are paid to the OCS throughout a several years period.

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